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DIVISON OF BOTANY

Bunt or Stinking Smut of Wheat*

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Bunt or Stinking Smut of Wheat

By

F. D. Heald and H. M. Woolman.

INTRODUCTION.

Bunt or stinking smut is beyond question the most serious disease of wheat in the Pacific Northwest. This trouble is very generally present in the wheat fields of Washington. It is the most destructive in the Palouse region of Eastern Washington and adjacent territory, and gradually decreases in severity as one passes from the more humid eastern part of the state to the semi-arid country. Comparatively few wheat fields can be found that are entirely free from smut. The disease may be present in traces only or a very high percentage of the heads may be destroyed. The amount of smut varies from year to year, but in general the disease has increased in prevalence during recent years. The general climatic conditions in the Palouse Country and the farming methods practiced have been favorable for the propagation of the fungus causing smut, so that the disease has attained greater severity than in any other part of the world, with the possible exception of Australia. Whitman County, which is the center of the area of severe smut infection of wheat, has produced the highest average yield of wheat per acre of any county in the United States. The question may be asked, what would the yield of Whitman County be without smut? It is our hope that the work of the Experiment Station will ultimately bring an answer to this question, not only for this favored county, but for all other parts of the state. While smut will probably never be eradicated from our fields, we have every reason to expect that careful methods and persistent efforts will so reduce its prevalence that it will become a minor factor in wheat production, instead of occupying the foreground as it does at present.

An estimate of the financial loss caused by wheat smut in this state would be purely a guess, but conservative producers place it in the millions of dollars for each season. The loss is four fold: first, the increased cost of production necessitated by seed treatment, soil sanitation and cultural practices designed to reduce infection; second, the reduction in yield per

acre; third, the lowering of grade or quality, and fourth, the loss from separator fires caused by smut explosions.

THE CAUSE OF WHEAT SMUT.

Wheat is attacked by three different types of smut which produce entirely different effects:

1. Loose smut caused by *Ustilago tritici* (Fig. 1.)
2. Bunt or stinking smut caused by either *Tilletia tritici* or *Tilletia foetans.*
3. Flag smut caused by *Urocystis tritici.*

The first species of smut is relatively rare in Wasington, while the third is entirely unknown in this part of the world.

Bunt or stinking smut is caused by two different species of microscopic fungi which live as parasites in the wheat plant. Both are essentially similar in their effects and their life history. *Tilletia tritici,* or the rough-spored variety, is the common stinking smut of the Pacific regions, while *Tilletia foetans,* or the smooth-spored species, is the one generally found in the Eastern United States.

The smut "berries" or "balls" from an infected head contain millions of minute bodies, the spores or "seeds" of the smut fungus. These reproduce the smut in somewhat the same way that a true seed develops into a new plant. In a threshing operation the dust that issues from the separator is laden with these spores in countless numbers, due to the breaking of many smut balls. Many of the loose spores not carried away will lodge upon the surface of normal grains, the groove, or "suture," and the "brush," or hair tuft at the terminal end, serving as resting places for large numbers. Wheat from an infected field will also contain many unbroken balls, and spores from these may be liberated later by the rupture of the thin enclosing membrane. A single smut ball of average size contains a sufficient number of spores to give one for each grain of wheat in five or six bushels, or if scattered over an acre would give 75 spores for each spuare foot. It takes eight smut spores to equal the diameter of a human hair. These comparisons are given to emphasize the minuteness of the smut spores, and call attention to the difficulty of excluding such minute bodies from the surface of seed wheat. Normal wheat grains from an infected field may have so many spores lodged on their surface as to give them a dark color, but other grains which show no difference in color to the naked eye may still contain a sufficient number of spores to produce a smutty crop if seed treatment is not practiced.

Fig. 1. The l ose smut of wheat caused by *Ustilago tritici.*

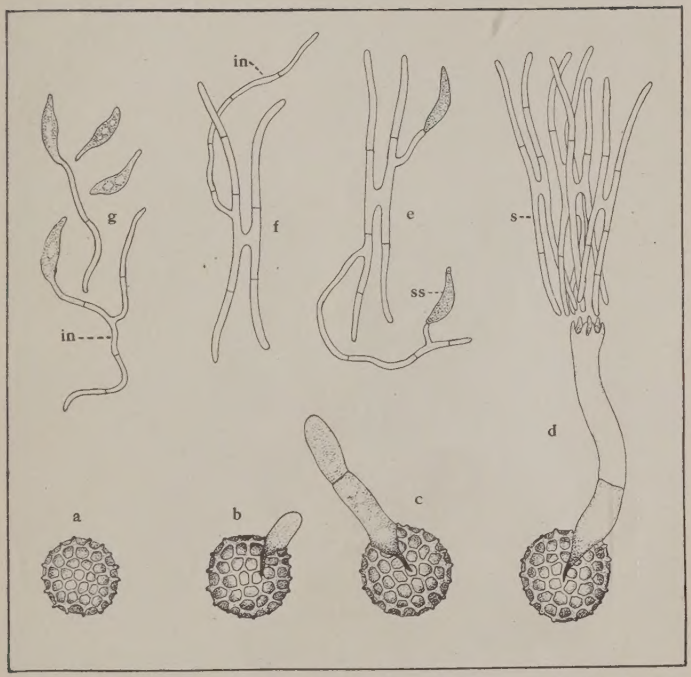

Fig. 2. Various stages in the germination of spores of stinking smut, *Tilletia tritici*. *a*, Spore surface showing characteristic reticulate ridges; *b*, spore in early stage of germination with young promycelium protruding from the ruptured spore wall; *c*, a later stage in the formation of the promycelium; *d*, mature promycelium with a tuft of H-shaped sporida, *s*, borne in its summit; *e*, a separated sporidium which has produced secondary sporida, *ss*; *f*, a separated sporidium which has given rise directly to an infected thread, *in*, *g*, several secondary sporida which have started to germinate or have produced infection threads.

When living smut spores are introduced into the soil with the seed wheat or exist in the soil in which smut-free wheat is sown a certain percentage of the wheat plants are likely to become infected. The smut spore germinates (Fig. 2) and produces first a stage of the smut plant in the soil. This first stage is called the promycelium and it never infects a young seedling direct, but gives rise to secondary spores or sporida (Fig. 2s) from which infection threads may arise, or secondary sporida (Fig. 2ss) may be developed which later produce infection threads. Under favorable conditions one or more infection threads penetrate the shoot of a young seedling and reach the growing point. Here the fungus threads keep pace with the growth of the plant, but give little or no external evidence of their presence until the production of heads, when they enter the ovaries and begin the development of the spores which reach maturity at or slightly before harvest time.

THE EFFECT OF SMUT.

Since this disease is caused by an internal parasite it is natural to expect certain responses to its presence. We should note first that the smut fungus is living at the expense of its host plant, the wheat. Its effect on the host may be summarized as follows:

1. The consumption of food.
2. The destruction of seed in the sporulating process.
3. The stimulating or retarding effect on normal physiological processes.

Badly smutted plants remain in many cases under size and produce fewer and smaller heads than normal plants. Observations and experiments lead to the belief that stools may harbor the smut fungus, when no smut develops in the heads. In such cases the mycelium, or vegetative body of the fungus, fails for some reason to reach the heads. The condition might be expressed in this way: In a young infected seedling there is a race between the smut fungus and the growing points of the flowering shoots in the upward growth. In some cases the fungus falls behind and never enters the heads, while in others it reaches its goal and penetrates the ovaries.

The presence of the smut causes certain deviations from the normal in the form of the infected heads. In the club varieties such as Hybrid 143 and others (Fig.3b), the normally compact head is changed to a more slender type. Fife or Blue Stem varieties and others of a similar type do not show such a noticeable change of form, but infected heads have a more

Fig. 3. *a*, Smutted and normal heads of Winter Fife; *b*, smutted and normal heads of Hybrid 108.

Fig. 4. *a*, Smutted and normal heads of Turkey Red. In this variety the awns on the smutted head break off easily since they are very brittle. *b*, Smutted and normal heads of Forty Fold.

loose or open appearance due to the divergence of the glumes (Figs. 3a and 4) caused by the enlargement of the smutted berries. Especially in the Fife and Blue Stem varieties the infected heads previous to maturity exhibit a darker green color, and remain green longer than normal heads. In some varieties the infected heads stand erect, when normal ones begin to droop as a result of the increasing weight of the ripening grain.

The most evident injury from wheat smut is due to the destruction of the grain or "berry" in the production of spores. The smut fungus enters the young ovary and uses up the food that is ordinarily accumulated and at the same time destroys the embryo, so that a fully smutted grain consists of only the brown outer seed layer (pericarp) enclosing the mass of smut spores.

A plant may be wholly or partially smutted, that is, all heads produced by a given stool may be smutted or only part of them may be invaded. The completeness of smutting varies with the different varieties and with the same variety fluctuates to some extent, apparently being influenced by the conditions which prevail during development. The following tabulations will show this variation (Tables I. and II.). A smutted plant frequently produces heads which are only partially smutted, that is, some grains may be normal, while others are infected. The normal grains may be variously distributed, bearing no definite relation to position. Partially smutted grains are sometimes very common (see Table III.) and the degree of smutting varies from those which show a minute black speck to those in which nearly the entire grain is involved. (Fig. 5). Heads have been found which showed only a single partially smutted "berry," all the others being uninfected. The question is naturally suggested at this point as to whether there may not be an invisible infection, since there are all degrees of visible infection. The production of partially smutted berries is much more common in some fields than in others, and suggests a possible explanation for some of the ineffective results of seed treatment.

HOW A CROP MAY BECOME INFECTED.

The information available at the present time shows that a crop may become infected with smut in a number of different ways. In some fields it is probable that the smut spores come from a single source, while in other fields their origin may be from two or more sources. Smut was originally introduced with the seed and many farmers are still planting smut every season with their seed wheat. Wheat

TABLE I.

Showing Variation in Number of Normal and Smutted Heads in Partially Smutted Plants.

	Hybrid 143		Forty Fold	
No. of plant	Normal Heads	Smutted Heads	Normal Heads	Smutted Heads
1	2	4	1	1
2	3	2	2	4
3	2	4	3	11
4	4	5	4	6
5	4	2	8	10
6	6	3	1	14
7	4	3	3	1
8	10	1	10	1
9	8	1	1	6
10	6	20	5	8

TABLE II.

Showing the Number of Completely Smutted and Partially Smutted Plants in Several Varieties. Six rod rows of each variety.

Variety	Number of normal plants	Number of completely smutted plants	Number of partially smutted plants
Red Russian	129	127	135
Forty Fold	133	155	158
Turkey Red	117	57	358
Winter Fife	43	414	82
Hybrid 60	37	494	58
Hybrid 108	45	299	63
Hybrid 123	34	394	72
Hybrid 143	15	369	20

TABLE III.

Showing the Relative Percentage of Smutted, Partially Smutted and Smut-Free Berries in 20 Heads.

Variety	Number of smutted berries	Number of partially smutted berries	Number of smut-free berries	Total No. of berries
Red Rusian	725	33	219	977
Forty Fold	735	35	253	1023
Hybrid 128	1001	11	128	1040
Early Wilbur	580	7	159	746

Fig. 5. *a*, Partially smutted berries of Red Russian wheat. *b*, Partially smutted berries of Hybrid 128.

taken from a smutty crop will have countless numbers of loose spores adhering to the grains, in many cases visible to the naked eye, in other cases too few to be noticeable except by the aid of a microscope.

Wheat from an infected field will contain a certain number of unbroken smut balls, the number varying with the severity of infection and the variety of wheat. These unbroken smut balls are always a source of danger, even when the seed is treated with fungicides previous to sowing. In seed treatment the fungicide does not reach the interior of the smut ball, and they are frequently broken during the seeding process and the spores scattered over the grain.

The partly smutted berries are also a source of contamination, and if present in seed wheat to any amount may render seed treatment ineffective. The partly smutted grains show little or no variation from normal in either size or weight and would not be removed in the ordinary processes of cleaning.

There are also chances for the infection of a crop with smut if absolutely smut-free seed is employed. In such a case there are two possible sources of infection: first, soil infection from a previous smutty crop; second, soil infection from wind-blown spores. If wheat follows wheat and the first crop was smutted, the soil will contain large numbers of smut spores. Some of these are separated spores scattered at the time of harvest or later but many are in the form of unbroken smut balls, in many cases connected with the head. Following a harvest of a smut-infected field a sufficient number of smut heads have been found to give 570,000 spores to each square inch of surface. It is known that the spores in unbroken balls lying in the open fields on the surface of the ground retain their viability for at least one year, or from harvest to the following fall seeding time. Our experiments have shown, however, that the separated spores from crushed smut balls lose their infective power in from two to three months provided the soil is moist and loose. (Table IV.), and in no case do they survive a winter. It is not known how long the spores remain viable in uncrushed smut heads when plowed under. Some tests, however, of smut heads which had been buried through two winters failed to give any viable spores. Their duration of life under such conditions probably depends upon temperature, depth, moisture, and compactness of soil.

There is no longer any doubt that under present conditions smut is extensively disseminated by the wind in the wheat growing regions of Washington. The evidence for this is two-fold: first, the actual determination of the number of

TABLE IV.

Showing the Persistence of the Infective Power of Smut Balls When Placed in the Soil.

Dates of planting 1914	Dates upon which crushed smut balls were placed in the soil 1914-1915				
	May 9	June 26	July 30	October 7	March 3
	Percentage of infected plants				
Sept. 14			60.0		
Sept. 17	16.0	56.0	83.0		
Sept. 19		45.0	88.0		
Sept. 28	10.0	44.0	78.0		
Oct. 3	11.0	20.0	62.0		
Oct. 8		32.0	70.0		
Oct. 11	0.7	0.7	53.0		
Oct. 18	3.0	12.0	61.0		
Oct. 25	0.0	2.0	14.0		
Oct. 31	0.0	0.0	6.0		
Nov. 5		0.5	8.0		
Nov. 9		0.0	5.0	72.0	
Nov. 23		0.0	2.0		
1915					
March 6			0.0		79.0
March 8			0.0		84.0
March 13			0.0	0.0	95.0
March 22			0.0	0.0	71.0
April 18			0.0	0.0	9.0
April 24			0.0	0.0	2.3
May 8			0.0	0.0	0.0

TABLE V.

Showing the Amount of Smut from Treated Seed Planted in New Soil on Various Dates.

Dates of Planting 1914	Percentage of smutted plants
July 30 to August 31, 19 plantings	0.0
September 1	20.0
September 14	21.0
September 17	41.0
September 19	60.0
September 28	36.0
October 5	27.0
October 11	14.0
October 25	0.7
October 31	0.7
November 5	0.0

spores carried by the wind under certain conditions, and second, the production of a smut-infected crop in new soil.

For example, at Pullman during the first week of September, 1915, 17,000 smut spores fell on each square inch of surface at a point one-quarter mile distant from the nearest wheat field. Smut spores can be found in abundance upon the surface of vegetation at varying distances from any

wheat fields. Twenty-five apple leaves taken from an orchard at least a quarter mile distant from the nearest wheat field, when collected and examined on September 9th were found to have over three million smut spores lodged upon their surfaces.

The results shown in Table V. are presented as evidence of infection from wind-blown spores. The tract used in this test had never had wheat grown upon it, nor had wheat been grown near it in recent years, while every possible care was taken to keep it free from smut. The seed was hand-threshed from selected smut-free heads, and was probably smut free. It was, however, treated for 20 minutes with a solution of one pound of bluestone and one pound of salt to 5 gallons of water, as an added safeguard against infection. Light rains began September 6th and the soil was well moistened by September 15th. No other explanation except wind-blown spores can be given for the high percentage of smut shown by the various plantings.

METHODS OF CONTROL.

It does not seem probable that wheat smut will be controlled by any single practice, but rather by the combined use of various methods. At this time emphasis should be placed upon five different lines of attack as follows:

(1) Crop rotation.
(2) The use of clean seed.
(3) Seed treatment with fungicides.
(4) Cultural practices.
(5) Breeding and selection of varieties.

1. Crop Rotation.

Failure to practice crop rotation is undoubtedly one of the main explanations for the general prevalence of smut in the wheat fields of Eastern Washington. Single cropping is not only a poor practice from the standpoint of soil exhaustion, but offers an opportunity for the gradual increase in severity of a disease after it is once introduced. In the interests of smut control we must urge more attention to rotation of crops. Wheat following wheat is very likely to be smutty for the reason previously outlined. Even with an intervening summer fallow, the smut from a previous crop may be a souce of infection. Many experiences show that a fall stubble crop is less liable to smut infection than a crop following summer fallow. The apparent explanation for this condition is the fact that the summer fallow becomes infected with wind-blown spores, while in a stubble crop, the wind-

blown spores as well as those originating from the previous crop are buried in plowing. It is not within the scope of this bulletin to discuss the various rotations that may be employed. These must be suited to the conditions which prevail in the various sections. Many farmers who are practicing a wheat, oats, summer fallow rotation, and are treating their seed, have generally reduced the smut to a considerable extent. It is worthy of note in this connection that experience on the Experiment Station farm where the rainfall is 23 inches has shown that summer fallowing is not an essential practice. It seems probable that a rotation which would eliminate summer fallow would help in solving our smut problem, and it is recommended for regions which do not require summer fallowing for the conservation of moisture.

2. The Use of Clean Seed.

If clean seed or properly treated seed had been used by all farmers we should never have had a smut problem. It is very apparent that too little care has been used in the selection of wheat for seed purposes. We can not advise the use of visibly smutted seed under any circumstances where it is possible to obtain clean stock. The farmer who has only smutted seed available would profit by selling his entire crop and purchasing smut-free or at least clean seed. If wheat showing unbroken smut balls must be used for seed it should be thoroughly cleaned to remove as many of these as possible. The danger from the few smut balls left in the seed wheat has already been pointed out. The difficulty of effecting their complete removal, either by the fanning mill or by the tank method of treatment, gives ample reason for placing emphasis upon the selection of clean seed.

Farmers who are not willing to adopt a general rotation for the reduction of smut would do well to set aside a seed plat of sufficient size to furnish their required amount of seed and practice a systematic rotation like wheat, oats, summer fallow or any other suitable sequence. With some attention to cleaning the separator, it should be possible by this method to always have a supply of clean wheat. The writers would advise threshing this seed wheat at low speed, to lessen the injury to the grains, since it is known that separator injury is an important factor in reducing the per cent of viable seed and also increases the injury from seed treatment.

The effect of separator injury upon the germination of wheat was discussed in some detail in a previous publication[1],

[1] Woolman, H. M., Stinking Smut in Wheat. Popular Bul. Wash. Agr. Exp. Sta., 73. 1914.

and will not be repeated here. In order to emphasize the danger of seed injury in theshing, the following facts based on this bulletin are presented: In a number of tests, hand-threshed wheat gave a germination percentage of 92-100, while for machine threshed grain the germination percentage ranged from 66-88. After a five-minute treatment in bluestone, one pound to 2½ gallons of water, the germination percentage of Forty Fold was as follows: hand-threshed, 100; threshed at low speed, 50; threshed at high speed, 35. While the strength of the copper solution was greater than that commonly employed in seed treatment, the figures show that grain threshed at high speed of the separator is injured more by seed treatment than seed threshed at low speed.

3. Seed Teatment.

Unless seed is known to be smut-free some treatment must be employed to kill the spores lodged upon the surface. If seed which does not contain unbroken smut balls is used and it is planted in an uninfected soil, the proper care in seed treatment should give either a smut-free crop or only traces of smut. High per cents of smut indicate either soil infection or imperfect treatment. Either physical or chemical agencies are in use for treating cereals for the various species of smuts. The hot-water treatment is quite effective for all smuts that are seed-borne, but the method is quite laborious and is only recommended when one of the chemical "steeps" is not effective. The hot-water method must be used for the loose smuts of wheat and barley in which there is an internal seed infection, but smuts like bunt of wheat, and the loose smuts of oats and barley in which the spores are superficial, can be treated to better advantage with chemical poisons. The principle of the chemical treatment is to use a poison which will kill the superficial spores of the smut and not materially injure the germinating power of the seed. Of the many different chemicals tried up to this time at this Station and elsewhere only a relatively small number have proved to be practical and at the same time effective. Many ineffective poisons are excluded on account of their cost. The two which have come into general use are copper sulfate, or bluestone and formaldehyde. The formulae for these two solutions are as follows:

1. Copper sulphate (bluestone) one pound, sodium chloride (common salt) one pound, water five gallons.

2. Formalin or a 40% solution of formaldehyde, one pound to 30 or 40 gallons of water.

These solutions should not be prepared by guess, but very accurately by weight and measure.

It should be expressly understood that we do not recommend the use of seed which contains unbroken smut balls. If however, necessity forces the use of seed of this type, the open tank method of seed treatment should be employed, the grain thoroughly stirred in the fungicide and all smut balls skimmed off. A convenient procedure is as follows:

1. Construct a water-tight tank or trough (8x2 feet and 14 inches deep is a good size).
2. Fill the tank two-thirds full of the fungicide.
3. Pour seed wheat slowly into the fungicide until the trough is nearly half full.
4. Stir thoroughly in order to float the unbroken smut balls to the surface.
5. Skim off the smut grains and destroy them.
6. Allow the grain to remain in the fungicide for at least ten minutes, then remove to sacks or pile in heaps and cover with moist sacks until the next day, when it should be used for seeding.

If formalin is used a new solution should be prepared every day as it loses its strength very rapidly. A stock solution of bluestone may be kept until it is used up as it does not lose strength.

If the formalin method is used and the seed is to be planted as soon as taken from the steep the period of immersion in the solution should be extended to thirty minutes to give a protective effect equal to that of the copper sulfate.

On the supposition that the seed employed is practically free from smut balls the following method can be employed, using either one of the solutions:

1. Put a sufficient amount of the solution (35 to 40 gallons) into a barrel to completely immerse a sack of seed or use a larger quantity in a tank.
2. Put seed to be treated into sacks (one and one-half bushels) and dip each sack into the solution, allowing it to remain ten minutes.
3. Remove the sack and drain, allowing the excess of the steep to run back into the barrel or tank. Replenish the solution as often as necessary from a stock solution, so as to always have the sack completely immersed.
4. Allow the treated seed to remain over night in the wet sacks and use the next day.

In seed treatment "safety first" is good policy, therefore the open tank method is strongly recommended.

Two effects of the "steeps" upon the seed should be borne in mind: first, the absorbtion of water causes more or less swelling of the grains; second, the toxic or poisonous action of the fungicide causes a reduction in the per cent of germination. In seeding due allowance should be made for the increase in size of the grains by setting the drill to sow more than the ordinary quantity of seed. Since the per cent of germination of untreated seed varies within wide limits, and the fungicides still further decrease the per cent viable, it is always advisable to make germination tests of the treated seed, and regulate the amount used per acre in accordance with this reduction.

The injurious action of the bluestone can be greatly reduced by soaking the seed in lime-water made by slacking one pound of quick lime and diluting to ten gallons. For careful work the sacks may be dipped in this solution for five to ten minutes immediately following their removal from the bluestone.

In case there is not a soil infection bluestone and formaldehyde seem to have about an equal protective action. In case of a soil infection, a condition which is found to be fairly common in Washington, the bluestone treatment seems to give slightly better results. This is explained by the fact that formaldehyde being a volatile poison, soon evaporates, while some copper is left behind on the seed coats, and passing into solution in the soil may inhibit or retard the germination of spores in the soil that are near to the young seedling. (See Table VI.).

TABLE VI.

Showing the Comparative Efficiency of the Bluestone and Formaldehyde Treatment in Preventing a Reinfection.

	Percentage of infected plants	
	Bluestone treatment	Formaldehyde treatment
Treated seed in smutty soil	16.3	50.1
Treated resmutted seed in clean soil	4.1	22.9

4. Cultural Practices.

Certain cultural practices are beneficial in reducing the amount of smut in all cases, while the value of others depends to some extent upon the source of the smut spores. The factors which always influence the amount of smut are (1) the temperature of the soil during the germinating period, (2) the

amount of soil moisture, and (3) the depth of seeding. Where seed-borne spores are the only sources of infection, attention to the three factors mentioned, will give the only cultural practices for reducing the amount of smut.

The temperature of the soil at the time of germination of the wheat is very important. Table VII. shows that the amount of infection from seed-borne spores when the mean soil temperature is 65° F. or over is much less than when it ranges between 65° and 40° F. It is also shown that still lower temperatures give a reduction in the amount of smut. A similar condition prevails when the smut is already in the soil (see Table VII.). The great reduction in smut in the later plantings in the infected soil was due in part to the death of the spores which had been in the soil for three months.

Our experiments have given some evidence that planting when there is just sufficient moisture to induce germination is a good practice, and even that dry planting and waiting for a rain is better than planting in a very wet soil. The relation of soil moisture to infection is still being investigated.

Our results during the past summer show that deep planting increases the amount of smut. This is true whether clean seed is used in an infected soil or smutted seed in a smut-free soil. (See Table VIII.).

When the source of smut spores is from a previous crop certain known facts should be taken into consideration: (1) The infection power from separated spores is limited to 2 to 3 months in moist soil; (2) spores in the unbroken balls may retain their viability for one year or more under natural field conditions: (3) separated spores do not live through the winter under normal field conditions. From these facts it seems certain that any operation on a smutty stubble field in the fall that destroys or crushes the balls and mixes the smut with the soil will be beneficial in reducing the amount of smut. Such practices as burning, rolling, dragging, disking, and heavy pasturing are suggested. It is recognized that burning is objectionable as a general practice, and should only be resorted to in extreme cases. Early spring plowing of land with tillage before the spring rains cease should give good results, while late plowing followed by tillage when the soil is relatively dry would offer an opportunity for much infection. In the former case a high percentage of the spores would succumb before seeding time, while in the latter case the liberated spores would remain viable until the fall rains, and would be ready to infect the crop. It seems probable that fall plowing preceeding summer fallow will also give good results, but it has not been tried to any extent. The

TABLE VII.

Showing Effect of Time of Planting on the Amount of Smut.

A. Clean (Hybrid 143) treated seed in soil heavily smutted on 7-30-14
B. Untreated and smutted seed (Hybrid 143) in clean soil.
C. Untreated and smutted seed (average of 6 varieties) in clean soil.

Date of planting 1914	Mean soil temperature during germination. °F.	A Percentage of smutted plants	B Percentage of smutted plants
August 24	69	28.0	3.1
August 31	67	33.3	3.9
September 2	66	25.5	5.5
September 17	55	83.0	91.3
October 3	52	62.1	99.1
October 8	50	69.4	96.6
October 18	47	44.9	97.5
October 25	46	15.4	93.6
November 2	42		92.5
November 9	39	5.4	88.6
November 23*	36	2.0	20.6
1915			C
April 23	54		25.6
May 3	59		16.2
May 8	56		14.7
May 15	53		34.2
May 22	60		10.6

*Did not come until spring.

TABLE VIII.

Showing the Effect of Depth of Planting on the Percentage of Smut. Hybrid 143.

Treated seed in smutted soil.

Depth of planting	No. of plants smut-free	No. of plants completely smutted	No. of plants partly smutted
0.5 in.	117	16	16
1.0 in.	83	20	58
1.5 in.	39	15	40
2.0 in.	25	32	39
2.5 in.	11	47	11
3.0 in.	9	45	5

Smutted seed in clean soil.

0.5 in.	29	1	0
1.0 in.	16	4	25
1.5 in.	35	28	14
2.0 in.	17	31	30
2.5 in.	16	88	25
3.0 in.	18	140	38

results given in Table IV. show that spores liberated in the soil during the dry period remain viable until the fall rains. Since it is the smut heads left near or on the surface of the ground that will furnish the spores for the infection of a following crop, an attempt should be made to bury these as completely as possible in plowing. For this reason the use of a jointer is recommended.

It has previously been shown that there is a general dissemination of smut spores during the threshing season. At present there is no way to prevent this and infection from wind-borne spores must be prevented by cultural practices. The summer fallow fields seem to be well seeded with wind-borne spores in the majority of cases. The practices suggested are: (1) seeding before the smut shower or if this is not possible at least before the fall rains; (2) replowing of the summer fallow after the first fall rains, and (3) late planting.

Early seeding of summer fallow is designed to eliminate or reduce not only the infection from the wind-borne spores, but is beneficial in case of seed or previous soil infection, on account of the high temperatures at that time of the year. (See Table VII.). By proper treatment of a summer fallow sufficient moisture can be retained at planting depth to insure prompt germination and growth. Even if the soil should be too dry for germination, planting to await the rain would be safer than planting soon after the fall rains begin. From the agronomic and farm management standpoints early planting has both advantages and disadvantages.

The advantages aside from the reduction of smut may be summarized as follows:

(1) The stand is always well developed and reduces the soil washing in the early spring.

(2) A greater part of the growth is made during the early spring, using moisture which would otherwise be lost by evaporation, and as a result the crop matures ahead of the season when burning is likely.

(3) The heavy fall growth furnishes a considerable amount of pasture.

Some of the disadvantages may be mentioned:

(1) The early planting comes at a busy season.

(2) The seed would have to be carried over from the previous harvest in most cases.

(3) There is greater danger of winter-killing and there is a chance for too heavy a growth of straw. The winter-killing can, however, be prevented by sufficient pasturing.

Early seeding has been practiced by various farmers, and they report a marked reduction in smut and are well satisfied with the results. Duling and Bishop of Garfield have followed this method for three years and report that the pasture alone netted them six to eight dollars per acre during the last season.

The replowing of summer fallow after the first fall rains is generally effective in reducing the amount of smut. It has been claimed by some that this practice reduces the yield, but this has not been true in any cases known to us. On the other hand there has been an apparent increase in yield. The summer fallow land of James Carnegie, near Pullman, was replowed during the fall of 1914, and a yield of 50 bushels of nearly smut-free wheat per acre was harvested during the past season.

Very late planting, that is, four or five weeks after the first good fall rains, is also an effective practice. This is shown by the results presented in Table V. and is substantiated by many farm observations. Fall tillage of summer fallow other than plowing seems to be beneficial, but since this is generally associated with later planting, it is rather difficult to say just how much of the benefit comes from the tillage and how much from the late planting.

5. Breeding and Selection of Varieties.

No smut-immune varieties of wheat are known but the standard varieties show varying degrees of resistance. This fact has suggested two lines of work: (1) the testing of established varieties to determine their comparative resistance and the selection of resistant strains if such can be found, and (2) the production of resistant varieties by crossing, which shall also possess the other desirable qualities. The second phase of this work offers much of promise, but it has not progressed to a point where definite statements can be made. The evidence concerning comparative resistance of varieties is somewhat conflicting and it will require more detailed tests for a number of years to give conclusive evidence. In the first place it should be noted that spring wheats generally suffer less from smut than winter varieties. This is not due to any superior resistance, but rather to the fact that they escape infection. If only spring wheats were grown our smut problem would largely disappear, but a return to this practice is not suggested, since the winter wheats are much more desirable.

A brief discussion will be presented of some results of our tests of a few winter varieties. The summary presented,

(see Table IX.), is the result of six plantings of each variety in three different locations. It will be noted that the relative resistance based on a count of plants showing infection is different from that shown by the count of heads. When infected and smut-free plants are counted, Red Russian shows the least smut, with Forty Fold second and Turkey Red third. The count of heads reverses the order, Turkey Red being best, while Forty Fold is second and Red Russian third. This is due to the fact that Turkey Red and Forty Fold produce many smut-free heads on infected plants. This indicates a capacity on the part of these varieties to outgrow an infection, and suggests one of the possible elements of resistance. It seems probable that the conditions which prevail during the growing season may have considerable influence on the per cent of smut in any given variety.

Essentially similar results have been obtained in the investigations conducted by the Division of Farm Crops as shown in Table X.

The evidence as it stands at the present time indicates that wheats of the Club type (*T. compactum*) are in general more susceptible than the common varieties (*T. vulgare*) with the long heads. The Winter Fife is apparently an exception to this, standing very close to the Club Hybrids in susceptibility, and other exceptions will probably be found as the investigations are continued. The greater susceptibility of the Club varieties to smut should not of necessity discourage their planting. It should be noted that some of the College Club Hybrids have excelled all others in both yield and quality.[1] This being true it may be advisable to grow them rather than some of the more resistant varieties which give a poorer yield. The search for resistant varieties suited to Eastern Washington is being continued.

SUMMARY OF RECOMMENDATIONS.

The control of smut will only be accomplished by the combined use of various practices. These are not presented in the order of their importance and they must of necessity be varied in different sections of the state.

1. More attention should be given to crop rotation, since single cropping to wheat is favorable to the continuation of smut.

2. The use of clean or smut-free seed is advised. It is a bad practice to use visibly smutted grain for seed, and es-

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1 Schafer, E. G., and Gaines, E. F. Washington Wheats. Bul. Wash. Agr. Exp. Sta., 121:1-16. 1915.

TABLE IX.

Showing the Comparative Resistance of a Number of Winter Wheats to Smut Infection.

Heavily smutted seed planted October 16, 1914; the figures represent the average from 6 plats of each variety in three different locations.

Variety	Percentage of clean plants	Percentage of smutted plants	Percentage of partially smutted plants	Percentage of smutted heads
Red Russian	36.0	35.2	28.8	45.8
Forty Fold	27.0	36.8	36.2	50.3
Turkey Red	22.0	11.2	66.8	40.2
Winter Fife	8.1	76.7	15.2	79.1
Hybrid 60	5.1	85.0	10.0	89.1
Hybrid 108	9.0	78.4	12.6	85.0
Hybrid 123	6.8	78.8	14.4	86.7
Hybrid 143	5.0	91.3	3.7	93.8

TABLE X.

Showing the Comparative Resistance of a Number of Winter Wheats to Smut Infection.[1]

Heavily smutted seed planted November 7. The figures represent results from a six-rod row of each variety.

Variety	Percentage of clean plants	Percentage of completely smutted plants	Percentage of partially smutted plants	Percentage of damage
Turkey Red*	49.36	0.0	50.64	4.56
Red Russian*	9.96	12.45	77.59	67.85
Forty Fold*	7.36	16.56	76.07	72.47
Triplet's Sister*	13.95	32.56	53.49	73.69
Turkey X Bluestem* ...	8.98	44.08	46.94	80.22
Hybrid 128**	8.75	68.17	23.08	86.63
Triplet*	1.91	41.19	56.90	88.13
Hybrid 108**	9.37	70.31	20.31	88.08
Jones Winter Fife*	5.41	74.20	20.39	89.35
Hybrid 143**	3.03	76.03	20.94	92.57
Turkey X Winter Fife*.	3.82	78.82	17.35	93.15
Hybrid 123**	1.67	50.63	47.70	93.89
Little Club**	2.26	87.22	10.52	96.24

**Average percentage of damage to Compactum types, 91.5.
*Average percentage of damage to Vulgare types, 80.7.

[1]This table was compiled by Mr. E. F. Gaines of the Division of Farm Crops and is based on tests made in the Cereal Nursery of the Experiment Station.

pecially so if the smut is in the form of unbroken balls. It is impossible to completely remove all unbroken smut balls either by the use of the fanning mill or by the tank method of seed treatment. The occurrence of partially smutted grains is an added source of danger that emphasizes the need of planting seed that is known to be smut-free.

3. Unless the seed is known to be smut-free, it should be treated with one or the other of the standard fungicides. The bluestone treatment has a slight preference for Washington conditions since it has some protective action in preventing infections from smut spores that are already in the soil.

4. The cultural practices which are known to prevent smut or reduce the per cent of infection should be followed as closely as possible. The most important facts to keep in mind are as follows:

(a) Early seeding either before the smut shower or at least before the fall rains begin will be likely to give a low per cent of infection or a smut-free crop.

(b) Seeding of summer fallow land during the first three or four weeks following the first fall rains will be likely to give a large amount of smut.

(c) Replowing of summer fallow reduces the amount of smut, if this operation and seeding take place after the first fall rains.

(d) If clean or properly treated seed is used, a fall stubble crop following a previously infected crop will show little smut if the plowing is done after the period of wind dissemination, that is, after the advent of the fall rains.

(e) Late fall planting will tend to decrease the amount of smut.

(f) Deep planting gives a larger amount of smut than shallow planting.

(g) Separated smut spores, that is, spores from crushed smut balls lose their infective power after 2 to 3 months in moist soil and never live through the winter under normal conditions. For this reason field operations which tend to crush the smut balls scattered during the harvest period are of importance.

5. The variation in susceptibility of varieties may ultimately make possible the selection of those which are highly resistant.